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EFFICIENCIES IN THE USE OF BITUMINOUS COKING COAL AS WATER-GAS GENERATOR FUEL

BY

W. W. ODELL

ILLINOIS COAL MINING INVESTIGATIONS
COOPERATIVE AGREEMENT

This paper represents work done under a cooperative agreement between the Bureau of Mines, Department of the Interior, the State Geological Survey Division of the State of Illinois, and the Engineering Experiment Station of the University of Illinois

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EFFICIENCIES IN THE USE OF BITUMINOUS COKING COAL AS WATER-GAS GENERATOR FUEL.

By W. W. ODELL.

INTRODUCTION.

Central District bituminous coals have been used to some extent during the past few years in Illinois and the surrounding States as water-gas generator fuel. The results obtained were encouraging enough to warrant further study of prevailing conditions and their causes, with the object of determining what changes in the construction of a water-gas set might be made to permit greater economies in the use of bituminous coal as generator fuel. The desirability of making as few changes as possible and of using present equipment as far as possible is recognized and has been kept in mind during the course of this study. High prices of oil and of coke and the tendency toward still higher prices increase the advisability of giving due consideration to this subject.

This paper is one of a series of publications dealing with an investigation relating to the manufacture of water gas. This investigation was conducted under a cooperative agreement between the Bureau of Mines, Department of the Interior, the State Geological Survey Division of the State of Illinois, and the Engineering Experiment Station of the University of Illinois.

Some of the data presented here have been published in other bulletins or technical papers of the Bureau of Mines. This duplication is made only when considered necessary to clarify the reasons for the conclusions reached.

ACKNOWLEDGMENTS.

The writer desires to acknowledge the assistance given in this study by the Public Service Co. of Northern Illinois, through the offices of Mr. C. W. Bradley; by Freyn Brassert & Co., of Chicago, whose engineers furnished information pertaining to the waste-heat boiler; by the Western Gas Construction Co., whose engineers prepared some of the drawings used as figures in this paper; and by O. P. Hood, chief mechanical engineer of the Bureau of Mines.

BITUMINOUS COAL AS GENERATOR FUEL.

DIFFICULTIES OF USING CENTRAL DISTRICT COAL.

In another publication of the Bureau of Mines[1] the operation and results when coal and coke are used as fuel are discussed, methods for operating with Central District coals are given, and the difficulties encountered are enumerated. In this paper, therefore, obstacles to the more general use of coal generator fuel are considered only as they pertain to the problem in hand.

Some of the bothersome obstacles that are of chief concern in the use of bituminous coal are enumerated below.

1. The coal, on coking, cakes and arches in the upper part of the generator.
2. For a given set of blasting conditions, there is a decrease in the volume of air that can be injected into the fuel on blasting.
3. Gas-making capacity is reduced, primarily because of the coking and arching of the coal and the lessened volume of the air that can be injected.
4. The volume and the heating value of the blast gas are increased or a given amount of blasting.
5. More fuel is used per 1,000 cubic feet of gas made.
6. Miscellaneous difficulties are encountered, including the formation of flues in the fuel bed, clinker troubles, smoke nuisance, sticking of valves, and sometimes carbon troubles.

When coke or other high-carbon fuel is used in the generator and carbureted gas with a heating value of over 600 B. t. u. per cubic foot is made, all the heat of combustion of the blast gas produced during the normal blasting of the generator is required for heating the checker chambers. As the quality of the gas or the gas standard is lowered, less oil is used per thousand feet produced and accordingly less heat is required for cracking the oil. Similarly, when a high-volatile fuel is substituted for coke, the thermal value and the volume of the blast gas are increased and a greater amount of heat than is normally required becomes available for use in the checker chambers. This condition is aggravated by the increased thermal value of the blue gas, which requires slightly less oil for carbureting. The balanced condition that prevails when coke fuel is used to make a rich gas is entirely upset when a "high-volatile coal" is substituted for the coke and a lower standard of gas is made. This upset condition is the prime cause of most of the difficulties encountered in using such a fuel and explains in part the burning out of metal chimneys, the overheating of the checker chambers, the high generator fuel per thousand feet of gas made, the tendency to use an excessive amount of steam during the run, and the tendency to use less air per run.

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[1] Odell, W. W., and Dunkley, W. A., Central District bituminous coals as water-gas generator fuel: Bull. 203, Bureau of Mines, 1923, 89 pp.

The next important factor that vitally affects operating results is the difficulty of heating or quickly coking the coal. The coal can not enter into the blue-gas reaction ($C+H_2O=CO+H_2$) until it has reached a high temperature; in other words, until it is coked. Since it takes longer for coal to be heated to the gas-making temperature than coke it follows that for a fuel bed of a given height, a greater per cent of relatively low temperature fuel is present in the generator when coal is used. This directly affects the gas-making capacity, reducing it.

The main obstacles encountered when bituminous coal generator fuel is used are in themselves the cause of other minor difficulties; and the remedy of the one automatically eliminates the other.

FACTORS IN SUCCESSFUL OPERATION.

For the successful use of coal generator fuel, it is first desirable to (1) heat the fuel more quickly or completely, (2) to utilize the heat of combustion of all the blast gas, (3) to increase the capacity, that is, make more gas per run, (4) to use in the finished gas as much of the volatile matter from the coal as possible, (5) to avoid the excessive formation of side clinkers or "edgings," (6) to eliminate excessive deposits of carbon in the carburetor, and (7) to use less fuel and steam per thousand feet of gas made.

OVERCOMING DIFFICULTIES OF OPERATION WITH COAL.

Some of the listed difficulties have been partly remedied, although not in an altogether satisfactory manner. The first four are overcome in part by the blow-run method of operating, which was instituted by the writer during the Streator experiments described in Bulletin 203 of the Bureau of Mines. This method consists of burning all the combustible blast gas in the checker chambers during blasting until the latter are hot enough for gas making, then closing the stack lid and continuing the generator blast for a determined fraction of a minute, allowing the producer gas generated to pass into the holder. The steam run is then made in the usual manner.

An increased percentage of down runs is the only means so far adopted to alleviate troubles from edgings and to bring the clinkers down to the grates. This method is of course most satisfactory for fuels with ash of the lowest fusion point.

RESULTS OBTAINED WITH BITUMINOUS COAL.

The results that have been obtained with bituminous coal fuel are given to aid the reader in understanding subsequent chapters.

Table 1 shows the practice and operating results at five plants where Central District coals were used as generator fuel. A comparison of results obtained with oven coke and with coal is given for Plant A. The blow-run method of operating was not used in these plants during the tests.

Table 2 gives the results obtained by the writer with mixtures of coal and coke. The figures in each column are the results of a particular day's operation.[2]

Some of the benefits derived from operating with the blow run are shown in Table 3. The oil per thousand cubic feet of gas made is slightly higher with this method of operating, but is not so high as in common practice with coke fuel used in the usual way. Figures obtained from various plants using different coals and mixtures are given "as reported" in Table 4.

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[2] For a more complete report of operation with mixtures of coal and coke, see Odell, W. W., Coal and coke mixtures as water-gas generator fuel: Tech. Paper 284, Bureau of Mines, 1922, 32 pp.

TABLE 1.—*Results obtained and operating conditions prevailing at five representative Central District gas plants where 100 per cent Central District bituminous coal is used as generator fuel.*

[Results as reported.]

	Plant A.		Plant B.[a]	Plant C.[a]	Plant D.[a]	Plant E[a b].
Size of set, feet	6	6	8	8½	8½	6
Kind of fuel used	Indianapolis oven coke, egg size.	Franklin County, Ill., lump coal.	No. 4 bed Indiana coal.	Franklin County, Ill., egg coal.	Jackson County, Ill., lump coal.	Williamson County, Ill., large egg coal.
Daily make, corrected, cu. ft.	398,000	398,000	603,000	852,000	914,500	172,500
Make per run hour, corrected, cu. ft.	27,245	21,750	41,800	38,700	50,800	23,000
Make per set hour, corrected, cu. ft.	24,000	19,500	39,100	35,500	45,720	21,600
Make per run hour per square foot of grate, cu. ft.	2,162	1,722	1,477	1,165	1,530	1,820
Daily operating time, including "cleans", hours	16.6	20.3	15.4	24	20	8
Make per run, cu. ft.	3,633	2,900	3,800	4,550	4,400	2,800
Cycle:						
Blow, minutes	[c] 3	[c] 3	2	3	2	3
Run, minutes	[c] 5	[c] 5	3	4	3	4
Cleaning time per day, minutes	120	120	60	120	120	30
Blast pressure, inches of water	18 to 20	18 to 22	16 to 17	16 to 18	20 to 22	17 to 18.
Air per minute during blow, cu. ft.	1,800	1,027	3,200	No meter	No record	1,200
Air per M feet, cu. ft.	1,485	1,060	1,680	do.	do.	1,285
Steam per minute:						
Up runs, lbs.	22	28	55	40	60	34
Down runs, lbs.	27	33	55	40	45	32
Steam per M cubic feet, lbs.	32	49	43.4	33	33.1	44
Up runs, per cent	60, all split	60, all split	Split, 60; down	50, up	50, up	66, up.
Generator fuel per M, lbs.	32.75	44.50	42.5	Approx. 40	42	46
Average weight of charge, lbs.	500	750	1,000 to 1,100	1,100	1,600 to 1,800	660
Charging interval, runs, approximately	4 to 5	4 to 5	5	5 to 6	8 to 9	5
Kind of oil used	32° to 36° gas oil	32° to 36° gas oil	28° to 30° gas oil	28° to 30° gas oil	28° to 30° gas oil	28° to 30° Texas.
Oil per M cubic feet, gals.	3.54	3.13	2.68	3.2	3	2.97
Heating value of finished gas, B. t. u.	600	600	575	565	588	578
Temperature at base of superheater, °F.	1,300° to 1,400°	1,300° to 1,400°	1,240° to 1,300°	1,300°	1,300° to 1,400°	1,300°

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[a] Data on practice with coke fuel not available for publication.

[b] Results at plant E are for a short day's run with the generator full of coke at the start and were obtained in experiments by the writer.

[c] Charging time deducted from run. Cycles per hour, 7.5.

TABLE 2.—*Results obtained and operating details prevailing when mixtures of coal and coke were used as generator fuel.*

	Illinois coal and St. Louis coke. Franklin County coal, No. 6 seam.				St. Louis retort coke.	
	67 per cent coal.	73 per cent coal.	77 per cent coal.	100 per cent coal.		
Gas made corrected, cubic feet	952,000	1,186,000	1,045,000	1,008,000	1,181,000	1,246,000
Number of runs made	112	136	134	151	136	153
Make per run, cubic feet	8,500	8,710	7,800	6,675	8,700	8,150
Make per run-hour, cubic feet	79,300	82,400	84,400	74,100	79,400	77,400
Make per set-hour, cubic feet	70,560	71,000	71,500	64,000	68,200	71,400
Make per square foot of grate per run-hour.	2,380	2,480	2,540	2,230	2,390	2,330
Oil per 1,000 feet, gallons	2.4	2.44	2.88	2.99	3.04	2.68
Fuel per 1,000 feet, pounds	42.4	41.0	46.6	48.0	33.3	
B. t. u.	528	535	550	555	543	533
Cycle: Blast	2 minutes 30 seconds	2 minutes 30 seconds	2 minutes 0 seconds	2 minutes 0 seconds	2 minutes 30 seconds	2 minutes 30 seconds.
Run	3 minutes 5 seconds	3 minutes 5 seconds	2 minutes 30 seconds	2 minutes 30 seconds	3 minutes 22 seconds	3 minutes 22 seconds.
Purge	0 minutes 0 seconds	0 minutes 0 seconds	0 minutes 0 seconds	0 minutes 0 seconds	0 minutes 8 seconds	0 minutes 8 seconds.
Blow-run	0 minutes 25 seconds	0 minutes 25 seconds	0 minutes 30 seconds	0 minutes 30 seconds	0 minutes 0 seconds	0 minutes 0 seconds.
Up runs and split runs	All split runs. ¾ minute up; 1¾ minutes down; ½ minute up.	All split runs. ¾ minute up; 1¾ minutes down; ½ minute up.	All split runs. ½ minute up; 1½ minutes down; ½ minute up.	Half split runs.[a] ½ minute up; 1½ minute down; ½ minute up.	All runs split 50/50	All runs split 50/50.
Air per minute, approximate	4,630	4,720	[c] 4,950	[c] 4,700	5,050	4,800
Air per 1,000 feet, approximate	1,460	1,450	1,500	[b] 1,620	1,500	1,500
Steam per minute, pounds	83.5	83.5	85	8	75.5	
Steam per 1,000 feet, pounds	27.5	27.2	26.2	30	28.2	25.8
Average weight of charge, pounds	1,920	1,700	1,920	1,400	1,600	1,600
Method of charging	Alternate, coal and coal with coke.	Alternate, coal and coal with coke.	1 buggy of coal, ½ buggy of coke.	Coal only	Coke only	Coke only.
Fuel [d]	Forked	Forked	Forked	Forked, but contained slack.	Shoveled	Shoveled.
Number of run-hours	12	14.4	12.4	13.6	14.88	16.1
Clinkering time	2 cleans, 1.5 hours	3 cleans, 2.3 hours	3 cleans, 2.2 hours	3 cleans, 2.15 hours	3 cleans, 2.45 hours	2 cleans, 1.35 hours.
Runs between clinker periods	55	45	45	50	45	70
Condition of clinkers	Tendency for wall clinkers to form. Grate clinkers were semirotten.	Tendency for wall clinkers to form. Clinkers on grates were semirotten.	Tendency for wall clinkers to form. Clinkers on grates were semirotten.	Wall clinkers formed	Hard. Some on side-wall.	Hard. On grate.
H_2S in raw gas, grains per 100 liters.	120	120	120	120	115	115
Total sulphur in finished gas, grains.	10.1	10.1	(z)	10	9.5	9.5
Air-blast pressure under grates	25″–26″	25″–26″	25″–26″	25″–27″	25″	25″
Steam pressure at boiler, pounds	125	125	125	125	125	125
Average oil per run, gallons	20.2	21.2	22.4	20	24.2	21.
Air per minute of blow-run	1,600	1,600	1,600	1,600	0	0

[a] First and third runs after coaling were up runs.
[b] High air per minute and air per 1,000 feet due to large size of coal and to air holes in fuel bed.
[c] Extra minute of blast after each coaling. Apparent higher rate of blast is due a relatively shorter duration of carbureter blast.
[d] The coke was shoveled in each case cited, and was rather small.

TABLE 3.—*Results obtained and operating conditions prevailing when 100 per cent Central District coal is used as generator fuel, showing the effect of the blow-run method of operating.*[a]

	Perry County, Ill., coal.		Franklin County, Ill., coal.		Williamson County, Ill., coal. A.		Williamson County, Ill., coal. B, with blow run.	Retort coke, without blow run.	Indianapolis oven coke.
	With blow run.	Without blow run.	With blow run.	Without blow run.	With blow run.	Without blow run.			
Daily make (corrected) . . . cu. ft.	165,000	155,000	180,000	162,000	163,000	172,000	172,000	184,000	279,000
Make per hour (corrected) . . . do.	26,000	21,700	28,000	23,200	25,600	23,400	24,800	23,000	25,400
Make per hour per square foot of grate . . . do.	2,069	1,735	2,260	1,860	2,048	1,875	1,980	1,840	2,016
Make per run (corrected) . . . do.	3,374	2,656	3,600	2,945	3,281	2,831	3,160	2,706	3,630
Cycle:									
Blow . . . minutes.	3	3	3	3	3	3	3	3	3
Blow run . . . seconds.	30	0	30	0	24	0	30	0	0
Steam run . . . minutes.	3.4	3.9	3.4	3.9	4	3.9	3.9	4	5
Air purge . . . seconds.	6	6	6	6	6	6	6	0	0
Up and down runs . . . ratio.	1 : 1	2 : 1	1 : 1	1 : 1	1 : 1	1 : 1	1 : 1	2 : 1	. . . .
Blast pressure during blow . . . inches.	17.5	18	18	18	18	18	18	16	19
Air per minute during blow, approximately . . cu. ft.	1,258	1,240	1,096	1,050	1,130	1,100	1,210	1,450	1,890
Air per minute during blow run . . . do.	1,016	0	975	0	980	0	800	0	0
Air per M cubic feet to generator, approximately . . . cu. ft.	1,300	1,400	1,200	1,150	1,260	1,280	1,370	1,600	1,560
Steam per minute, up run . . . pounds.	35	31	35	32	35	34	34	36	22
Steam per minute, down run . . . do.	33	33	37	34	34	32	32	34	27
Steam per M cubic feet of finished gas . . . do.	32.2	44	32.0	41.5	40.0	43.2	38.6	49	33
Generator fuel per M cubic feet . . . do.	47.3	52.0	42.3	48.8	43.0	46.0	44.5	44.5	36.7
Average weight of charge . . . do.	644	600	600	700	700	660	606	800	. . . .
Charging interval . . . runs.	5	5	5	5	5	5	5	5	. . . .
Oil per M cubic feet . . . gals.	3.04	2.84	3.02	2.78	3.24	2.97	3.06	2.94	3.58
Oil per run . . . do.	10–11	7.5	10–12	8–9	10–12	8.5	10–11	8	13
Daily operating time . . . hours.	6.35	6.90	6.45	7.0	6.36	7.35	7.15	8.0	11
Heating value of city gas, 1 mile from plant . B. t. u.	562	565	565	556	570	578	567	560	600
Hydrogen sulphide in unpurified gas . . . grains per 100 cu. ft.	150	150	160	160	200	200	420	100	. . . .
Nature of clinker . . .	Hard, some edgings brittle.	Rather soft.	Hard on grate, easily removed.		Hard on grate, easily removed.		Hard, brittle, easily handled.	Hard, excess steam necessary to make workable.	. . . .

---

[a] All of these results, with the exception of those in the last column, were obtained with the same set, having a generator with an internal diameter of 4 feet and operated under approximately the same conditions. The figures in the last column were obtained in a different plant, operating with coke fuel entirely; the latter are presented here for comparison. In calculating the air per M allowance has been made for the extra blasting after charging and for the air used during the purge and during the blow out. In calculating the steam per M the proper correction has been made for the time consumed in operating valves.

TABLE 4.—*Results obtained and operating conditions prevailing in various plants using 100 per cent coal as generator fuel.*

[Results as reported.]

	Plant A.	Plant B.	Plant C.	Plant D.	Plant E.	Plant F.	Plant G.
Internal diameter of generator ... feet	6	4	6½	5	8½	4½	6
Kind of fuel used	Clinton County, Ind., coal.	Franklin County, Ill., coal.	Perry County, Ill., coal.	Virginia coal	50 per cent anthracite; 50 per cent eastern gas coal.	Harlan County, Ky., coal.	Franklin County, Ill., coal.
Daily make, M cubic feet (corrected)	550	344	1,225	335	2,323	225	574
Make per running hour ... cu. ft.	45,250	21,700	55 700	28,450	110,500	20,245	50,000
Make per set hour, including cleans ... do.	41,600	19 300	52 100	27,130	98,000	19,200	45,840
Make per run ... do.	5,205	3,119	6 594	3,311	14,000	3,082	6,176
Make per running hour per square foot grate ... do.	1,600	1,736	1,688	1,445	1,950	1,280	1,785
Daily operating time including cleans ... hours	14.25	18	24	13.5	23.85	13.0	(?)
Cycle:							
Blow ... minutes	3.0	3.0	2.66	3	3	4.0	3.0
Blow run ... do.	0.5	0.0	.33	0	0	0.5	0.5
Steam run ... do.	3.25	4.9	3.84	4	4	3.75	3.75
Purge ... do.	0.25	0.1	.16	0	0	.25	.25
Cleaning time per day ... do.	69	120	94	40	160	60	69
Blast pressure ... inches water	17 to 20	16 to 24				14	17 to 20.
Air per minute during blow ... cu. ft.	2,800	1,250			10,000 (?)	1,400	2,800
Air per minute during blow run ... do.		0			0	1,200	(?)
Air per M cubic feet finished gas ... do.	1,410	1,155			2,140 (?)	2,010	(?)
Percentage of up runs	33	66				66	33
Steam per minute up ... pounds	60	25.8		40 (?)	128	34	60
Steam per minute down ... do.	60	28.8		40 (?)	123	31	60
Steam per M cubic feet finished gas ... do.	34.6	42.5		48.4 (?)	35.8	40.1	36.4
Generator fuel per M cubic feet ... do.	43.4	43.4	41.9	42.29	33.57	46	39.14
Average weight charge ... do.	800 to 1,000			500		1,175	800 to 1,000.
Charging interval ... runs	4 to 5			3		8 to 10	4 to 5.
Kind of oil used	Texas, 27	Oklahoma, 30 to 36.	Texas, 28	Oklahoma, 32 to 34.	Mexican, 34	Texas, 30	Texas, 27.
Oil, introduced in minutes	3	4½	3.5	3	3	4	3
Oil per M cubic feet ... gals.	3.00	3.22	3.19	2.90	2.94	2.90	3.07
Heating value of finished gas ... B. t. u.	565	600	568	600	602	18 c. p.	565
B. t. u., where taken	Plant	1 mile from plant	Plant	Plant	Plant		Plant.
Nature of clinker	Hard, but easily handled.	Easily removed.	Hard, considerable edgings.	Brittle, close to grates.	Soft	Mostly ash on grate.	
Carbon in ash and clinker	Very little	Considerable		Practically none.	Considerable	None	
Hydrogen sulphide in raw gas ... grains per 100 cu. ft.	200		150	70			

ECONOMY EFFECTED WITH COAL AS GENERATOR FUEL.

Results already obtained with coal as generator fuel show that a marked saving can be effected; that is, with war-time prices for coke, oil, and coal, the cost of making 1000 feet of gas will be less when coal is used. With the present prices of "gas-oil" and coke, the continued economy that can be realized by substituting coal for coke is evident. Figure 1 shows the possible economy in the use of coal as compared with coke fuel.[1a] No allowance has been made for differences in capacity, purification, or air requirements

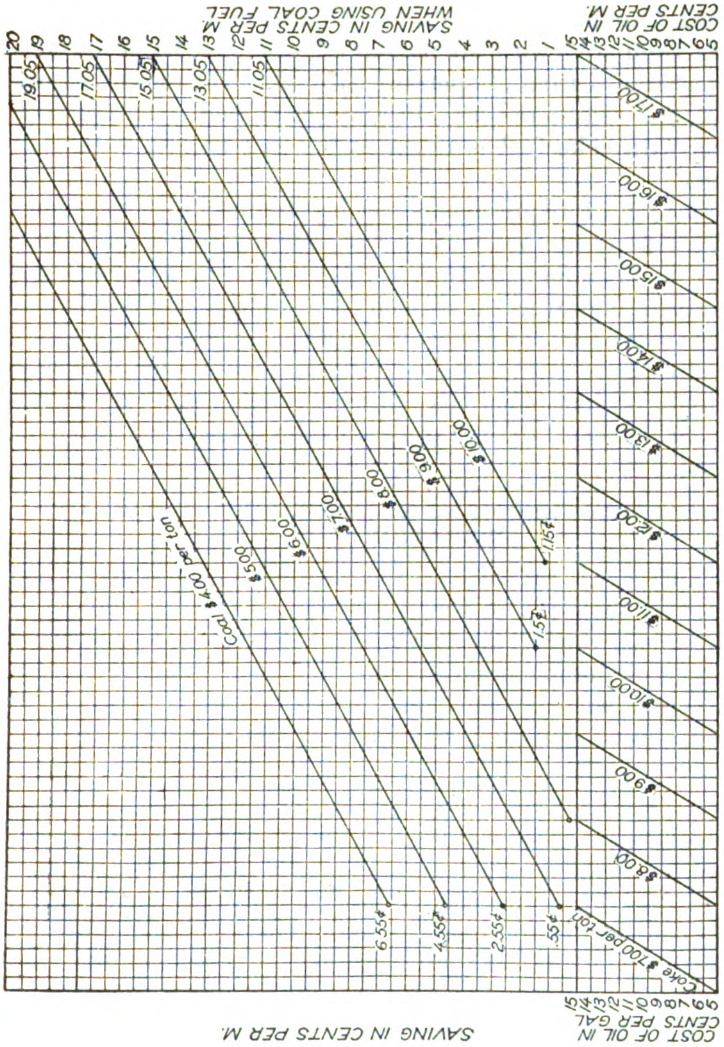

FIGURE 1.—Saving in cents per thousand feet when bituminous coal instead of coke is used as generator fuel.

These data are based on the following:

		Coal fuel.	Coke fuel
Fuel used per M.	lbs.	40	33
Oil used per M.	gals.	3.0	3.2
Steam used per M.	lbs.	35	35

The saving possible when using coal figured as described may be found as follows: Follow the line representing the price of coal horizontally until it intercepts the line for the cost of coke at the particular plant, then follow the vertical line from this point to the line representing the cost of coal and thence horizontally to the right to the saving in cents per M.

[1a] The capacity is considered to be the same for each fuel and no allowance is made either for the greater volume of air blast required per M during operation with coal fuel, or for sulphur-purification difficulties. Since the capacity obtainable with coal fuel is not the same in all plants, due allowance should be made in calculating exact costs. This correction must be computed separately for individual plants.

with different fuels. These differences will necessarily have to be considered separately for each individual plant, since at some plants the capacity is not reduced during operation with coal and in others a reduction of 10 to 20 per cent is noted. In the latter the actual operating cost is higher per thousand feet, and there is a corresponding reduction in the possible saving per thousand feet. The data given in Figure 1 are based on the use of 33 pounds of coke per thousand feet, as compared with 40 pounds of coal per thousand feet when the blow-run method of operating is used. The air and steam requirements are considered as alike for each fuel. The oil per thousand feet with coke fuel is taken as 3.2 gallons and with coal fuel, 3 gallons.

This difference in oil requirements can be obtained with the blow-run method of operating, but with the regular method of operating the difference in favor of coal fuel is three-tenths of a gallon. In the latter instance, however, the capacity is materially reduced when comparison is made with the results obtained with Eastern coke.

According to Figure 1, it is evident that in plants remote from a source of supply of good oven coke but close to a source of supply of a cheap, suitable coal, the use of coal in the generator is particularly indicated.

METHODS OF OVERCOMING PRESENT DIFFICULTIES OF OPERATION.

From the foregoing, the seat of the troubles encountered when using coal fuel is obviously in the generator. Since the volume of water gas produced during the run depends upon the temperature and the volume of the incandescent fuel and upon the time of contact of the steam with the fuel, any improvement or increase of output of blue gas must come chiefly from changes in these conditions.

DEPTH OF FUEL BED.

When a change in the depth of the fuel bed is considered, the conditions desirable for making a steam run seem quite the opposite of those best suited for blasting. In order to produce blue gas containing a minimum amount of CO_2 by the reaction $C + H_2O = CO + H_2$ with but little of reaction $C + 2H_2O = CO_2 + 2H_2$ taking place, it is desirable to have as deep a fuel bed as practicable heated to as high a temperature as feasible. On the other hand, to produce the least possible amount of CO during blasting, it is desirable to have as shallow a fuel bed as possible and to blast as rapidly as possible. For making a gas of high heating value from high-carbon fuel, the combination found in common practice has proved quite satisfactory; that is, all the combustible blast gas produced on blasting the fuel to the desired temperatures is required to heat the checker chambers enough to crack the oil. When the gas standard is lowered more combustible blast gas is produced than is required. A high-volatile fuel increases the production of such gas enough to impair the efficiency of operation. Decreasing the depth of the fuel bed and increasing the rate of the blast would perhaps benefit this condition, but it would simultaneously further reduce the gas-making capacity, since it is not feasible to shorten materially the operating cycle. In fact, the opposite result is sought; that is, an increased capacity. When the fuel bed is deepened somewhat, it offers greater resistance to the introduction of air and there is more combustible matter in the blast gas, although the gas-making capacity is perhaps slightly increased. Neither of these changes in the depth of the fuel bed seems to solve the problem.

Various attempts have been made to overcome this obstacle by the use of double generator sets. The fuel is blasted from the bottom of each generator, and the steam usually enters at the bottom of one, passing up through it and then through the fuel in the second generator. Here the effect of a deep fuel bed during the run and a shallow one during blasting is realized. Although such a process offers certain advantages it has not been adopted in this country. In fact some of the large plants that installed twin generators have replaced them by the modern single generator water-gas set.

VOLUME OF FUEL IN GENERATOR.

One possible improvement of conditions without changing the depth of the fuel materially involves increasing the volume of fuel in the generator by increasing the internal diameter of the generator. This apparently would be of particular advantage when using coal fuel, for it increases the area of the zone of complete combustion, decreases the resistance to the introduction of a given quantity of air per minute, increases the quantity of heat stored in the generator for a given amount of blasting, and decreases the linear rate of travel of the fuel in the generator for a given rate of fuel consumption.

An oversize generator should permit the production of the normal amount of blue gas, when coal is used, without unduly increasing the linear rate of travel of the fuel. It should accordingly offer an opportunity for the fuel in the upper part of the generator to become hotter.

The "make" of blue gas is materially reduced in the ordinary operation with coal fuel, due chiefly to a decreased average temperature in the generator, to the decreased air input during blasting, to clinker conditions, and to the superficial heating of the partly coked coal during the blast.

TIME OF CONTACT—TEMPERATURE.

The time of contact of the steam with the incandescent fuel is of importance and is best considered as a function of the temperature. Both the velocity and the completeness of the water-gas reaction increase with the temperature and with the time of contact. The time of contact required for the production of satisfactory blue gas increases very rapidly as the temperature decreases from 1,200° C. (2,192° F.). Slight changes in the temperature of the fuel below 1,200° C. are decidedly more effective than slight changes in the time of contact. To obtain a material benefit from increasing the time of contact of the steam with the fuel would require such an increased fuel volume that the mechanical disadvantages would probably offset the benefits.

Obviously, the maximum temperature that can be conveniently used in water-gas generators is limited. Since the use of higher temperatures is neither necessary nor desirable it seems that the output of a set might more readily be augmented by increasing the percentage of high-temperature fuel in the generator, this being requisite for increasing the make with coal fuel. The increase may come from a change in methods of operating, an increase in the size of the generator, or a provision for air blasting the upper part of the fuel.

UP RUNS AND DOWN RUNS.

When coal is used, an increased number of down runs has been found necessary to prevent green fuel from passing out with the ash and to help keep side clinkers down. This is due chiefly to the difficulty of rapidly heating the coal, to the purely superficial heating of the partly coked coal, and to the practice of using excess steam during the run. Benefits have unquestionably been derived from this practice, although the make during a down run is not ordinarily as great as during an up run. In the writer's opinion, it would be preferable to make more up runs if the conditions in the generator could be regulated in another way. Any benefits that may be derived from forcing the tarry vapors down through the fuel bed, as during down runs, are probably more than offset by the chilling of the green fuel—which should be heated as quickly as possible—and by the decreased make. The temperature of the gas leaving the generator is at a maximum during down runs, and considerable heat is absorbed from the fuel in the upper part of the generator.

HOT-AIR BLAST.

The employment of hot-air blast has been suggested as desirable with coke fuel, but it is not considered feasible with iron grates. Conditions are so different, however, when coal is substituted for coke in the generator that, in the writer's opinion, the use of preheated air for blasting is not only desirable but is under certain conditions feasible. The additional heat generated in the lower part of the fuel bed would, it seems, eliminate the necessity of making so large

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a percentage of down runs, improve clinker conditions, or at least put the clinkers on the grate instead of on the generator wall, increase the gas-making capacity, and reduce to a minimum the percentage of fuel in the ash. Under these conditions, the fuel should carbonize earlier in its course through the generator and offer less resistance to the introduction of air during blasting.

How hot this preheated air could be without damaging the set can not be said. Undoubtedly the limit will vary somewhat—depending on the rate of the blast, the kind of coal used, the method of operating, and the quantity and melting point of the ash—but could be readily determined by experiment.

OIL COKE OR TAR COKE.

Carbonized oil or tar residuum has been and is being used as generator fuel in some plants, which are obtaining more readily very high temperatures in the generator. Residuum has been used with coke fuel to minimize the difficulties from side clinkers. At some of the plants where success in reducing side clinkers was reported the carbon was not uniformly mixed with the coke but was admitted to the generator one charge at a time after every third or fourth charge of coke; that is, approximately 20 to 25 per cent of carbon was charged.

This remedy for side clinker is mentioned here, not because it is cheap but because some plants may be so situated that other methods can not be conveniently utilized and the periodical use of carbon fuel with coal fuel would be the better and perhaps the cheaper method. It is well to note that the oil used per thousand feet is not noticeably higher when carbon is mixed with the coal than when the fuel is 100 per cent coal.

ASH SOFTENING POINT—RELATION TO UP AND DOWN RUNS AND TO SIDE CLINKERS.

The fusion temperatures of coal ash have considerable influence on clinkering and an important bearing on operating results and on generator capacity.

Coal ash, being a mixture of a number of substances, does not have a single definite melting point. The gradual softening and fusion of the ash when heated is not merely the successive melting of the various ash constituents but a more complicated process involving the formation of new and more fusible compounds. It has been shown further that the softening point is affected by the amount and form of iron in the ash,[2] by the rate of heating, and by the atmosphere in which the ash is heated. A number of tests showed that the maximum difference in softening temperatures due to different atmospheres ranged from 134° to 396° C. It is evident that through the reduction of the iron content to the metallic state a slag or fluid ash might freeze on passing from one zone to a slightly hotter zone of different atmosphere.

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[2] Fieldner, A. C., Hall, A. E., and Feild, A. L., The fusibility of coal ash and the determination of the softening temperature: Bull. 129, Bureau of Mines, 1918, pp. 20-21.

TABLE 5.—*Softening point, softening interval, and flowing interval of ash from some Central District coals.*

Samples.		Softening point.		Softening interval.		Flowing interval.	
Laboratory No.	Source.	°C.	°F.	°C.	°F.	°C.	°F.
30889	Franklin County, Ill	1,200	[a] 2,190	120	220	90	160
30892	.....do	1,240	2,260	100	180	110	200
30893	.....do	1,320	[a] 2,410	50	90	80	140
30880	.....do	1,060	[a] 1,940	60	110	170	310
30883	.....do	1,180	2,150	70	130	100	180
30888	.....do	1,100	2,010	100	180	140	250
30879	.....do	1,050	1,920	80	140	180	320
30863	Williamson County, Ill	1,190	2,180	28	50	120	220
30864	.....do	1,070	1,950	90	160	70	130
30872	.....do	1,100	2,010	40	70	30	50
30873	.....do	1,160	2,120	70	130	110	200
30874	.....do	1,280	2,330	130	230	90	160
30875	.....do	1,330	2,420	50	90	60	110
31033	Perry County, Ill	1,140	2,090	100	180	110	200
31034	.....do	1,150	2,100	70	130	180	320
31035	.....do	1,180	2,160	40	70	140	250
31036	.....do	1,120	2,050	70	130	150	270

[a] See Bull. 209, page 23.

NOTE.—The "softening interval" is the difference between the softening temperature and the temperature of initial deformation. The "flowing interval" is the difference between the softening temperature and the fluid temperature.

Table 5 gives the temperatures of softening and the temperature intervals of softening and flowing of ashes from a number of Central District coals. It shows considerable range of softening temperatures for coals in the same district. These determinations were made on small cones molded from powdered ash moistened with dextrin solution. The "cone," or triangular pyramid was 1 inch high and had base edges three-sixteenths inch thick. The softening temperature is that at which the cone fuses down to a spherical lump. The initial deformation temperature is the temperature at which the first rounding of the apex of cone is noted. The softening interval is the difference between the softening temperature and initial deformation temperature. The flowing interval is the difference between the fluid temperature and softening temperature.

The effect of different atmospheres on ash-softening temperatures is shown in Table 6.

TABLE 6.—*Results of tests to determine comparative effects on softening temperatures of ash of atmospheres of air, of water vapor, of carbon dioxide, of carbon monoxide, of equal parts of hydrogen and water vapor, and of equal parts of carbon monoxide and carbon dioxide.*

No. of ash sample.	Fe_2O_3.	Softening temperatures.						
		Oxidizing atmosphere.			Reducing atmosphere.		Atmosphere of equal parts of H_2 and H_2O.	Atmosphere of equal parts of CO and CO_2.
		Air.	Water vapor.	CO_2.	H_2.	CO.		
	Per cent.	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
16243	35.9	1,335	1,313	1,347	1,370	1,295	1,080	1,085
15844	19.0	1,490	(*a*)	(*a*)	(*a*)	(*a*)	1,255	1,315
16586	11.8	1,322	1,322	1,327	1,402	1,375	1,250	1,275
15848	7.0	1,425	1,370	(*a*)	1,360	1,331	1,283	1,325

[a] Above 1,400° C.

Atmospheres consisting of mixtures of H_2O vapor and H_2 (30 to 70 per cent H_2O vapor) or of CO and CO_2 (10 to 75 per cent CO) tend to lower the softening-point temperatures; and oxidizing or strongly reducing atmospheres give the highest, as they reduce the iron present to the metallic form and minimize its fluxing effect. Iron tends to exist in the ferric form in oxidizing atmospheres.

TEMPERATURE ZONES.

Different oxidizing and reducing atmospheres prevail in the water-gas generator at some time during the cycle in various parts of the fuel bed. Figures 2 and 3 show the approximate temperature zones as well as conditions prevailing during the blast. The actual relative depth of the zones depends on the method of operating, the method and rate of blasting, the quality of steam used during the run, the manner in which the fuel is spread on the fuel bed, and other variables. In the early stage of blasting, the gases formed are chiefly CO_2 and N, which are favorable to a high ash-softening temperature, but the temperatures throughout the fuel bed are perhaps not high enough for the influence of this atmosphere to be of much significance. As the blasting proceeds, the per cent of CO increases and the temperature in the fuel is higher. This atmosphere is more favorable to a low ash-softening point. It is not surprising then, as the fuel passes down and is consumed, for the semifluid ash to freeze as it approaches the oxidizing zone, and when in contact with the cooler side wall, to stick to it as clinker.

During a day's operation, zone 1 gradually becomes the ash and clinker zone, and when the fuel is low the location of the zones may be more nearly as shown in Figure 3. It follows that the side clinkers formed as described will accumulate higher in the generator as the operation progresses.

When an up run is made, zone 1 is being cooled by the steam and zone 2 and part of zone 1 are cooled by the endothermic reaction $C+H_2O=CO+H_2$. The atmosphere is strongly reducing in zones 3 and 4, but enough H_2O and CO_2 probably are present in the lower zones to favor low ash-softening temperatures, the effect of which would be greater in zone 2. This zone would accordingly be one that is continually favorable for such a condition during the blast or up runs.

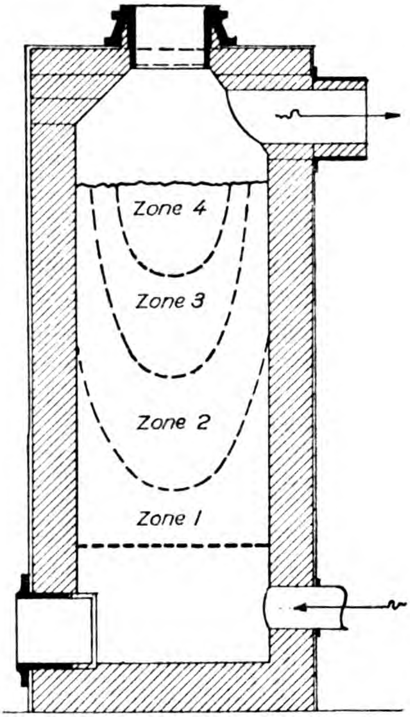

FIGURE 2.—Approximate location of temperature zones during blasting with a clean fire. Zone 1 is hottest and zone 4 coolest.

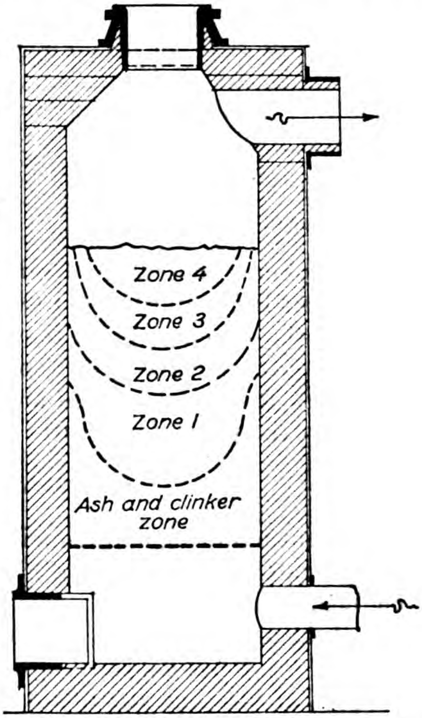

FIGURE 3.—Approximate location of temperature zones during blasting with a dirty fire. Zone 1 is hottest and zone 4 coolest.

During down runs, a somewhat different condition exists. Here the gas is heated to its maximum temperature after it has passed through the upper zones and is strongly reducing in zone 1. Therefore in zone 1, during the early stages of the run when but little undecomposed steam passes through the fuel bed, conditions favor a high ash-softening temperature. In zones 2 and 3 steam and CO_2 are present in sufficient quantities for the opposite conditions to prevail. During the latter part of the run enough steam and CO_2 probably are present in the whole fuel bed to favor a low ash-fusion point.

On down runs the zones do not have the same shape as shown in Figure 2 but they are more nearly horizontal. With a clean fire they may be convex instead of concave (see Fig. 5). Obviously then, the upper part of zone 1 in Figure 2, the part near the wall, will be in a hot reducing zone during the entire down run, a condition favorable for low ash-softening points. Evidently, in making down runs there is something more to consider than merely cooling the upper part of the fuel bed and retaining a higher temperature in the lower zones. That side clinkers are not so prevalent when a large percentage of down runs is made is perhaps due to both of these factors rather than to one.

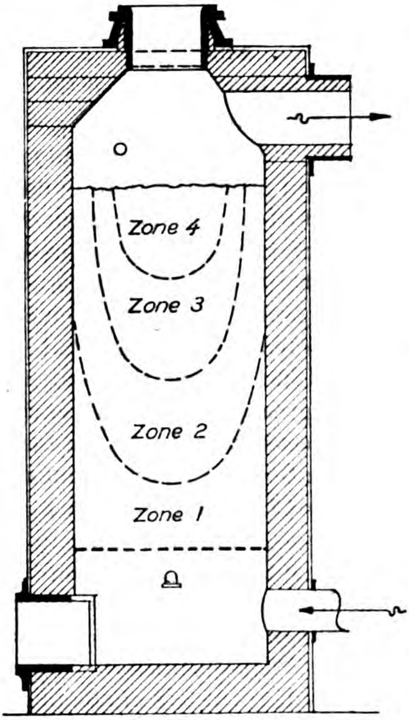

FIGURE 4.—Approximate location of temperature zones during an up run with a clean fire.

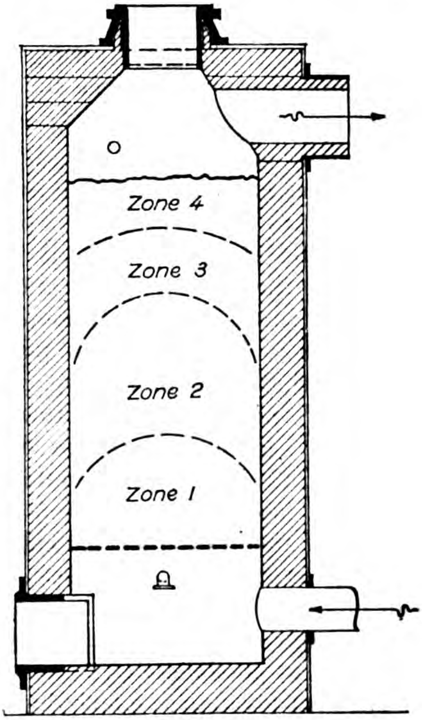

FIGURE 5.—Approximate location of temperature zones during a down run with a clean fire.

Operators have voiced great divergence of opinion as to the benefits derived from down runs; some feel positive that they aggravate the wall clinkering and others are equally positive that they lessen it. It is conceivable that by the use of various fuels with different ash-softening points and dissimilar ash constituents and the employment of different operating conditions wide variations in the formation of clinker might be obtained. The lower the ash-softening temperature and the greater the difference in softening temperatures due to changes in the gaseous atmosphere, the greater should be the benefits from making down runs, at least so far as clinkering is concerned. Accordingly, it would be more desirable to give attention to these conditions and to evolve a best method of operation for a particular set of conditions rather than to operate according to the rule of thumb methods developed in plants where conditions are entirely different.

EXCESS STEAM DURING THE RUN.

The primary water-gas reaction may be written as follows:

$$\begin{array}{ccccccc} C & + & H_2O & = & CO & + & H_2. \\ \text{12 lbs.} & & \text{18 lbs.} & & \text{28 lbs.} & & \text{2 lbs.} \end{array}$$

Equivalent at 60° F. to 378 cu. ft. CO + 377 cu. ft. H_2 = 755 cu. ft. of gas.

The quantity of blue gas in 1,000 cubic feet of carbureted gas is not usually greater than this, although dependent on the quality of finished gas made; therefore it may be said in general that 18 pounds of steam are actually required per thousand feet of carbureted gas. During the run, however, as the temperature in the generator decreases, the quantity of steam that passes through the fuel undecomposed increases. A common figure for steam used per thousand feet, with coke fuel, is 35 pounds, practically 100 per cent in excess of that calculated above. When coal fuel is used, the tendency in ordinary practice has been toward a still greater excess. An excess over the 18 pounds per thousand feet is necessary and perhaps more desirable than it may seem on first consideration. A small amount of steam is used in the reaction $C+2H_2O=CO_2+2H_2$, in which 18 pounds of steam produce 565 cubic feet of gas. There appears to be a limit, not the same for all fuels, below which the steam consumption can not be reduced profitably. It is desirable, from a consideration of generator conditions and blue-gas output only, to operate as near this limit as possible.

The heat loss due to employing an unduly large excess of steam per thousand feet of gas as made is as follows:

Assume the steam used in a particular case is	lbs. per M..	45
The actual steam required is, say	do....	35
Unnecessary steam consumption is accordingly	do....	10

The assumed value for steam consumption is not abnormal but represents the actual figure frequently obtained in plant operation.

The steam leaves the checker chambers at approximately 1,350° F. The total heat in 10 pounds of steam at 1,350° F. and 1 pound pressure is, roughly, 17,350 B. t. u. The heat already furnished in the steam at 100 pounds pressure is $1,189 \times 10 = 11,890$ B. t. u. The loss of heat supplied from the generator per thousand feet of gas made due to this excess steam is 17,350 B. t. u. − 11,890 B. t. u. = 5,460

B. t. u. This is equivalent to 0.46 pound of coal per M. If the prevailing boiler practice is the evaporation of 7 pounds of water per pound of coal the total fuel loss per M. is $0.46 + \frac{10}{7} = 1.89$ pounds. This amount of fuel can sometimes be saved by giving attention to unnecessary use of steam.

OIL CRACKING—CARBURETING.

The statement has been made that the tarry vapors from the coal in the generator cause an increased amount of carbon deposits in the checker chambers, and particularly in the carburetor. This is probably true, but not to the extent that might be supposed. The quantity of carbon deposited, regardless of the kind of fuel used, depends on the method of operating, the oil used, the effectiveness or efficiency of the oil spray, and other factors. Since the oil-cracking efficiency (B. t. u. efficiency) is as great or greater than with coke fuel, and the tar yield is increased 20 per cent, it is possible that less carbon is deposited from oil cracking. With the excess steam that is commonly used with coal fuel, it is probable that some of it reacts in the checker chambers with hydrocarbons similar to the following: $C_2H_4 + 2H_2O = 2CO + 4H_2$. It is not known exactly to what extent these reactions take place or how much of the excess carbon deposited is from the tar.

Frequently, when additional carbon seems to be formed, the carburetor is blasted in such a way as to burn out most of it. This can be done quite effectively, but since in most gas plants no more blast air is available than is required for normal operation, use of an excess in the carburetor will evidently rob the generator. Burning out carbon by blasting the generator is, therefore, undesirable if a more satisfactory method can be devised.

A method that has been frequently tested is to pass air through the checker chambers by natural draft during clinkering periods—either by opening a door at the top of carburetor or by removing the cap on top of the carburetor through which oil spray passes. Some carbon is burned out by this method, but the disadvantages are often greater than the benefits. The air is admitted directly after a run, when the bricks in the upper part of the carburetor are cooler than at any other time. The carbon on these bricks is not completely burned, but the air is heated enough for the combustion of the carbon in the lower part of the carburetor; thus the temperature in this chamber after the "burning out" of the carbon is very high at the bottom or lower part and relatively cool in the upper part where a high temperature is desired. Furthermore, the smallest amount of carbon is burned from the part of the carburetor where the heaviest deposits are; that is, on the upper courses of checker brick.

Another disadvantage in so burning out the carbon is that after the process is finished and the fuel is blasted, the blast gases are burned in the carburetor to heat its upper part, and the lower part, which is already overheated, becomes dangerously hot.

The writer suggests a method that seems safer and more efficacious. This consists of burning out the carbon by natural draft in the opposite direction; that is, opening a door near the bottom of the carburetor for an air intake and providing a means of exit for the CO_2 and N_2 formed during combustion at the top of the shell. A small door is also opened on the bottom of the superheater during this period; thus the carbon is burned out of this shell also and the checkers in it are not usually overheated, for the carbon deposit is small and the volume of air relatively large. The injection of steam to prevent overheating is not necessary.

WASTE-HEAT BOILERS.

Various kinds and types of waste-heat boilers have been used in water-gas plants with varying degrees of success. They may be divided in two classes, those utilizing the sensible heat of both blast and carbureted gas and those utilizing the sensible heat of the blast gas only.

Boilers of the former class have been failures so far. This is due chiefly to the fact that tar is deposited in the tubes or on them, according to the type of boiler, and not only decreases the boiler efficiency but necessitates frequent shutdowns for cleaning out. The so-called tar deposit is not tar, literally, but a carbonaceous pitchy mass, a distillation product of tar, and is removed only with difficulty.

Boilers of the other class have been operated with fair success. Some of the newer types have proved very effective in economizing the waste heat—sensible heat—of the blast gas.

In the past, when a gas of high candlepower was made with coke as generator fuel, no appreciable amount of combustible matter appeared in the waste-stack gas from the superheater. When a high-volatile bituminous coal is used as generator fuel and gas of less than 600 B. t. u. is made considerably more combustible matter is produced than is desirable in the ordinary operation of a set; and, therefore, some is present in the waste-stack gas. The writer offers the suggestion, based on the foregoing, that a waste-heat boiler be used with sets utilizing coal as fuel and that a suitable combustion chamber be supplied for burning the excess combustible blast gas.

The first questions evident in considering the use of a combustion chamber are:

How much combustible gas is available for burning in such a chamber?

What will the saving be?

Is it safe?

An analysis of the blast gas at the generator lid throws considerable light on its quality during various stages of blasting. Figure 6 shows the quality of the blast gas at all stages during blasting. The gas produced during the last stage of blasting is in composition a very rich producer gas. Now, it is known that when coal fuel is used the checker chambers are sufficiently heated before the generator fuel is hot enough to generate satisfactory water gas in desired quantities. A measure, then, of the quantity of combustible blast gas produced in excess of requirements, when the fuel is being blasted to the desired temperature, can be made by merely noting the time required to blast the fuel after the checker brick is sufficiently hot, and by recording the rate of blast during this stage and during the rest of the blast period. In measuring the volume in

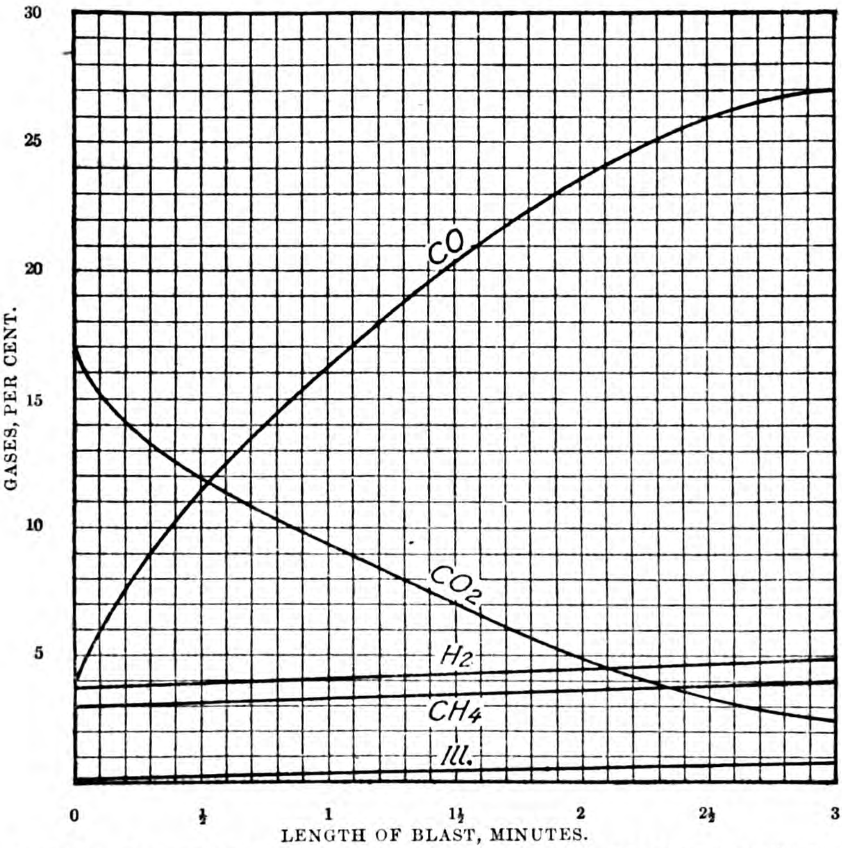

FIGURE 6.—Analyses of blast gases at different stages of the blast, as sampled at the generator lid, showing the changes as the blast progresses for a particular set of conditions. The shape of the curves will vary according to the fuel used, the quantity of air and steam used per thousand feet, and the general method of operating.

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this manner only an amount of air sufficient for complete combustion is used as carburetor blast, for any great excess affects the accuracy of the test. The following example uses assumed figures:

Combustible gas produced in excess of requirements.

	Cu. ft.
Rate of blast:	
First minute	1,600
Second minute (carburetor blast on)	1,200
Third minute (carburetor blast on)	1,200
Following one-half minute (carburetor blast off)	800
Total air used	4,800
Air blast for heating generator only	800
Per cent of total generator air	16⅔

Since 1,500 cubic feet of air is normally used in the generator per thousand feet of finished gas made, the 4,800 cubic feet of air correspond to:

$$\frac{4{,}800}{1{,}500}=3{,}200 \text{ cubic feet of carbureted gas.}$$

The generator air per thousand feet used in excess of the requirements for generating producer gas (combustible blast gas) to heat the checker chambers then is:

$$\frac{800}{3.2}=250 \text{ cubic feet.}$$

The blast gas that can be produced from this 250 cubic feet of air is approximately:

$$250\times1.3=325 \text{ cubic feet.}$$

Therefore there is available for use outside the water-gas set 325 cubic feet of 150 B. t. u. gas for every 1,000 cubic feet of carbureted gas made.

In actual practice, with a given set of conditions, the volume of gas available per thousand feet of gas made will depend primarily on the quality and quantity of the volatile matter of the coal, on the size and character of the coal used, and on the standard of quality of the finished gas. It is, of course, somewhat dependent on the method of operating and other variables. In actual experiments with coal fuel it has been found that more than 275 cubic feet of producer gas are so available. This figure was obtained with rather low temperatures in the generator and with less than 1,400 cubic feet of air per thousand feet to the generator. When so operating as to increase the air per thousand feet to 1,500 cubic feet or more there will be more producer gas per thousand feet available for use outside the set. The temperature in the fuel bed should then be higher, if care is taken not to use more steam per thousand feet, and the output of finished gas per unit of time should be greater.

The writer estimates that with some of the high-volatile Central District coals the excess of producer gas generated during blasting will be 360 cubic feet per thousand feet of carbureted gas. Operation with coals containing less volatile combustible matter gives a smaller excess of producer gas. Moreover, if gas of a higher standard than 560 B. t. u. is made the excess of producer gas is smaller.

POSSIBLE ECONOMY IN USING A WASTE-HEAT BOILER WITH A COMBUSTION CHAMBER.

In calculating the saving effected by the use of a waste-heat boiler with a combustion chamber, it is most convenient to take as an example a set of specified size with definite operating practice. The figures presented here are for a special set designed to produce a maximum yield of 2,500,000 cubic feet of gas per day. The operating conditions assumed are also given.

Assumed operating conditions.

Estimated make of gas:	Cu. ft.
Per day (20 hours running, 4 hours cleaning fire)	2,500,000
Per running hour	125,000
Per run (8 runs per hour)	15,625
Cycle—3-minute blast and 4-minute run—	
Blast required to generator:	Cu. ft.
Per thousand feet	1,500
Per hour (in even thousands)	187,000
Per run (per cycle)	23,440
Estimated maximum amount of producer gas (combustible blast gas) made per hour available for use in combustion chamber ... cu. ft.	45,000
Heating value of producer gas (see Table 6) ... B. t. u.	145.6
Low heating value of producer gas (see Table 6) ... B. t. u.	139
Average temperature of—	°F.
Blast gases leaving set	1,360
Waste gas leaving waste-heat boiler	760
Drop in temperature of gases passing through boiler	600

The analysis and figures for combustion of the producer gas available for burning in the combustion chamber of the waste-heat boiler are given in Table 7.

TABLE 7.—*Combustion data and average analysis of a generator blast-gas produced during the last stage of blasting a water-gas generator, when using a high-volatile Central District bituminous coal.*

	Cubic feet.	B. t. u.		Oxygen required.	N_2.	CO_2 formed.	H_2O formed.	B. t. u.—low value.	
		Per cu. ft.	Total.					Per cu. ft.	Total.
			Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*		
CO_2	2.20	0	0	0	0	2.2	0	0	0
Ill	.38	1,588	603.4	1.14	4.31	0.76	0.76	1,515	575.7
CO	27.47	323.5	8,886.5	13.74	52.00	27.47	0.00	323.5	8,886.5
CH_4	3.15	1,009	3,178.4	6.30	23.84	3.15	6.30	910.0	2,866.5
H_2	5.80	326.2	1,892.0	2.90	10.98	0.00	5.80	275.0	1,595.0
N_2	61.00	0	0	0	(61.00)	0	0	0	00
	100.0	....	14,560.3	24.08	91.13	31.38	12.86	....	13,923.7

B. t. u. per cubic foot = 145.6—low value (fractions dropped) $= \frac{13,923.7}{100} = 139$ B. t. u.

Theoretical quantity of air required for the complete combustion of 100 cubic feet of this generator blast gas is 115.2 cubic feet.

There are 14.24 cubic feet of the gas in 1 pound.

100 volumes of gas yield 198.57 cubic feet of combustion products, calculated to 60° F. Weight per cubic foot (at 60° F.) = 0.07658 pound.

Figures on combustion of the gas available.

The heat of combustion of the 45,000 cubic feet of producer gas is:

$$(45,000)\ (139) = 6,255,000 \text{ B. t. u.}$$

The heat already supplied as sensible heat in the producer gas at 1,360° F. is:

$$\begin{array}{cccc} \text{Weight.} & \text{Mean specific heat.} & \text{Temperature. °F.} & \text{B. t. u.} \\ \left(\frac{45,000}{14.24}\right) & \times .280 \times & (1,360-60) & = 1,150,280. \end{array}$$

The total heat of and in the producer gas is:

$$6,255,000 \text{ B. t. u.} + 1,150,280 \text{ B. t. u.} = 7,405,280 \text{ B. t. u.}$$

Volume of air required for combustion, allowing 20 per cent excess air, is:

$$45,000 \times \left(\frac{115.2}{100}\right) \times \left(\frac{6}{5}\right) = 62,208 \text{ cu. ft.}$$

This amount of air is equivalent to 497 cubic feet per thousand feet of finished gas made.

The total volume, calculated to 60° F. of the products of combustion, then is	cu. ft.	99,725
The total weight is	lbs.	7,914

The heat remaining in this waste gas from boiler is:

$$\begin{array}{cccc} \text{Weight.} & \text{Mean specific heat.} & \text{Temperature. °F.} & \text{B. t. u.} \\ 7,914 & \times .250 \times & (760° - 60°) & = 1,384,950. \end{array}$$

The economy made by the combustion of this excess producer gas is:	B. t. u.
Total heat of and in the producer gas	7,405,280
Heat remaining in waste gas from boiler	1,384,950
Recoverable heat	6,020,330

This is equivalent to the hourly evaporation of $\frac{6,020,330}{971} = 6,200$ lbs. of water from and at 212° F. and $= \frac{6,200}{34.4}$ or 180 boiler h. p.

This is equivalent to 4 pounds of fuel per thousand feet of gas made, considering the fuel to have a calorific value of 12,000 B. t. u. per pound.

ADDITIONAL ECONOMY FROM UTILIZATION OF SENSIBLE HEAT OF BLAST BURNED IN CHECKER CHAMBER.

The additional economy realized due to the sensible heat of the blast gas that is burned in the checker chambers can be calculated when the average analysis of the total blast gas generated is known. The quality of this gas varies, not only with the fuel used, but also with the method of operating; hence no particular analysis will apply to all conditions. The analysis used in this computation is given in Table 8 and represents a blast gas that may be produced with a high-volatile bituminous coal.

Table 8.—*Combustion data and average analysis of the total blast gas produced during a single blast with high-volatile bituminous coal as generator fuel.*

	Parts by volume per 100 cu. ft.	O_2 required.	CO_2 formed.	H_2O formed.	N_2	B. t. u. low value.	
						Per cu. ft.	Total.
CO_2	10.2	0	10.2	0	0	0	0
CO	15.6	7.8	15.6	0	29.5	323.5	5,046.6
Ill. (C_2H_4)	.5	1.5	1.0	1.0	5.7	1,515	757.5
H_2	3.0	1.5	.0	3.0	5.7	275	825.0
CH_4	3.0	6.0	3.0	6.0	22.7	910	2,730.0
N_2	67.7	0	.0	0	67.7	0	0
Total	100.0	16.8	29.8	10.0	131.3	....	9,359.1

1 volume of air produces 1.16 volumes of blast gas; 1 volume of blast gas requires 0.80 volume of air for complete combustion and 1 volume of blast gas yields 1.71 volumes of burned gas.

The low heating value of this blast gas is, according to the table, 93.6 B. t. u. per cubic foot.

The additional economy realized due to the sensible heat in the gases that are burned in the checker chambers may be calculated as follows:

Figures on combustion of the gas available.

Total air blast to generator per hour=187,000 cu. ft.

Total producer gas generated=187,000×1.16=216,920 cu. ft.

The theoretical amount of air required for the combustion of this gas is (216,920) (0.80) =173,530 cu. ft.

However, a 20 per cent excess air was allowed for the portion of this producer gas burned in the combustion chamber. Adding this amount, the total air required for combustion of all the producer gas made is 173,530+10,400=183,930 cu. ft.

The total secondary air per thousand feet, then$=\frac{183{,}930}{125}=1{,}470$ cu. ft.

The heat recovered, then, will be the sensible heat in the total blast products, from 1,360 to 760°, less the sensible heat already credited. In other words, it is the recoverable sensible heat in the blast gases from combustion in checker chambers.

The gas burned in checker chambers=216,920−45,000=171,920 cu. ft.

The air used in checker chambers=183,930−62,200=121,730 cu. ft.

The volume of combustion products=280,870 cu. ft.

The weight=22,520 lbs. The total heat present at 1,360° F. is as follows:

Weight.		Mean specific heat.		Temperature, ° F.		B. t. u.
22,520	×	.262	×	(1,360−60)	=	7,670,300

Heat remaining in the waste gas at 760° F.=22,520×.251×(760°−60°)=3,956,760

The heat recoverable in the waste-heat boiler then is:

	B. t. u.
Total heat present	7,670,300
Heat remaining in waste gas at 760° F.	3,956,760
Heat recoverable	3,713,540

This is equal to 29,710 B. t. u. per M.
2.5 lbs. of fuel per M (12,000 B. t. u. fuel).
3,824 lbs. evaporation per hour from and at 212° F.
111.2 boiler h. p.

The total heat recovered, then, operating as described, is the sum of the estimated economies, and is equivalent to 180 boiler h. p.+111.2 boiler h. p.=291.2 boiler h. p. Allowing 2 per cent loss, the net saving is:

$291.2\times\frac{100}{102}=285.5$ boiler h. p., or 6.49 lbs. of fuel per thousand feet of gas made. (Fuel having a calorific value of 12,000 B. t. u. per lb.=evaporation of 80.2 lbs. of water, from and at 212° F., per M.)

This represents the fuel saving possible when operating with Central District bituminous coal with a waste-heat boiler, as compared with the best figures obtainable, operating with the same fuel without a waste-heat boiler.

The reader should note that the use of such a boiler permits the blasting of the generator fuel to a better gas-making temperature, which in turn allows a greater "make" per hour. It is estimated that the make should equal that obtained with coke fuel in the same size set (not same size generator) and the labor costs per thousand feet will compare more favorably with the costs when coke fuel is used. This is an appreciable saving in itself and is an amount which varies in different plants. It is not credited here.

The saving in dollars and cents due to the waste-heat boiler may be figured in two ways—as generator fuel recovered or as boiler fuel saved. Figuring from the latter viewpoint and considering boiler fuel worth \$3.50 per ton in the bin and the usual boiler evaporation of 7 pounds of water from and at 212° F. per pound of coal, the yearly saving would be: $\frac{(2{,}500)(365)(80.2)}{7\times 2{,}000}\times \$3.50=\$18{,}295.62$ yearly.

In this equation 2,500 represents the make per day in thousands of feet; 365, the days of the year; 80.2, the evaporation per thousand feet; 7, the pounds of evaporation in the works boiler in average practice; 2,000, the pounds in a ton; and \$3.50, the cost of boiler fuel per ton. Shutdowns to clean the boiler and rechecker the set should also be considered. The moisture in the blast gas has not been considered in the above calculations. The specific heat of water is high, more than twice that of stack gas, hence any appreciable amount of the latter present in the blast gas results in a greater economy from the use of the waste-heat boiler.

Using coke fuel, an evaporation of 38 pounds of water per M from and at 212° F. has been obtained when operating with an ordinary waste-heat boiler in which only the sensible heat of the blast gas was economized. The total evaporation given above is 80 pounds per M. The difference in favor of coal fuel is $80-38=42$ pounds per M, or the thermal equivalent of 3.4 pounds of fuel having a calorific value of 12,000 B. t. u. per pound.

Since calculations of this nature are always somewhat open to question, and errors are frequently difficult to detect, the following simple calculation is offered as a rough check on the figures given:

	Pounds.
Generator fuel per M (14,000 B. t. u. coke)	30
Generator fuel per M (12,000 B. t. u. bituminous coal)	42
Difference	12

These figures—30 and 42 pounds—represent particularly good practice in each instance. The actual figures frequently found with ordinary operation are 40 and 55 pounds, respectively. The blow-run method of operating is not considered in this comparison, since conditions are entirely different in the latter instance.

Coal per M that would be required if the consumption was proportionate to the heat of combustion $=\frac{14,000}{12,000}\times 30=35$ pounds per M. Excess fuel consumption when using coal fuel as compared with high-grade coke is 42 pounds $-$ 35 pounds $=$ 7 pounds.

High fuel consumption when using coal is due chiefly to two causes when the fuel bed is free from "blow holes." the volatile matter in the coal and the excess steam used per M.

The figure 42 pounds per M is, however, based on conditions where the steam used is very little greater per M than with coke.

The 7 pounds difference, then, is due chiefly to the volatile matter of the coal which affects results in three ways, increasing the combustible matter in the blast gas; increasing the calorific value of the blue gas, thereby reducing the total amount of heat required to heat the checker chambers since less oil is required; and increasing the total volume of blast gas per M.

Considering the blue gas, when coal is used to have a heating value of 335 B. t. u. and that 800 cubic feet of such gas are required for 1,000 cubic feet of carbureted gas, the amount of fuel consumed in producing blue gas (the amount in excess of that required with coke fuel) can be readily calculated as follows:

B. t. u. per foot of blue gas—	
Coal fuel	335
Coke fuel	300
Difference . . . B. t. u.	35
Blue gas in 1,000 cubic feet of carbureted water gas, using coal fuel, cu. ft.	800

Additional heat furnished to the carbureted gas per M then is 800 B. t. u. $\times$ 35 B. t. u. $=$ 28,000 B. t. u. and is equivalent to $2\frac{1}{3}$ pounds of the coal fuel.

The approximate amount of excess heat in the blast gas is 7 pounds $-2\frac{1}{3}$ pounds $=4\frac{2}{3}$ pounds of coal per M of carbureted gas.

The estimated possible economy from the use of coal as figured above, 3.4 pounds per M, is therefore not higher than should be expected.

TYPES OF WASTE-HEAT BOILERS.

The old type of horizontal tubular waste-heat boilers or those slightly inclined from the horizontal have not proved entirely satisfactory for use with water-gas sets. Repeated attempts have been made to obtain operating efficiency with them, but the desired results did not materialize. One of the chief sources of trouble in their use is the insulating deposit which collects rapidly on the tube walls, decreasing the rate of heat transfer to the boiler (boiler efficiency). These tubes are not so readily cleaned as might be supposed. The unsatisfactory performance of these horizontal boilers has been probably one cause of the gas industry's lack of interest in the recovery of waste heat.

The present tendency seems to be toward the use of vertical fire-tube boilers, or those slightly inclined from the vertical. No attempt is made in some of these to recover the sensible heat of the carbureted gas but merely that of the blast gas, and in such instances the tubes are kept clean and bright by the particles of carbon entrained in the gas. One boiler of this type which has so far proved very satisfactory, compared with others, is shown in Figure 7. This boiler was originally designed for utilizing the sensible heat of

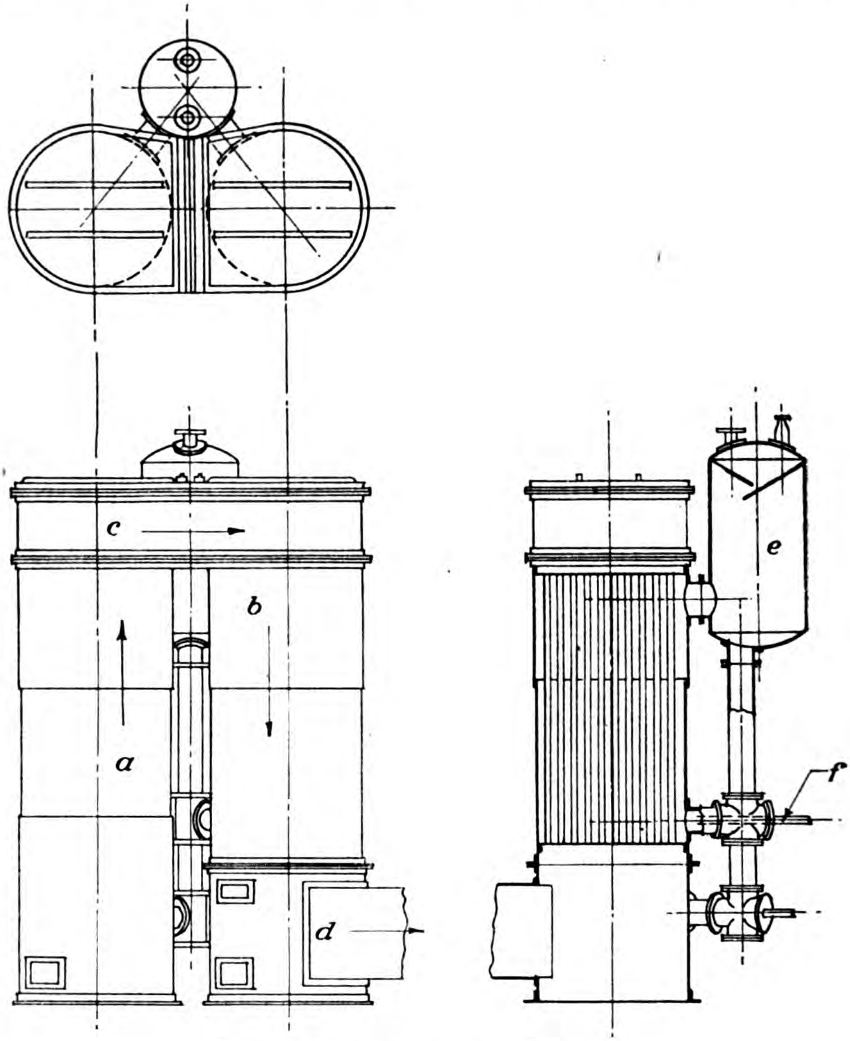


FIGURE 7.—Waste-heat boiler for stack gas only.

furnace-blast gas and not particularly as an adjunct to a water-gas set. However, the success attending its use warranted its adoption as a water-gas (blast-gas) waste-heat economizer. A boiler of this type has been in use in the Detroit city gas works for several years and has proved satisfactory. Although it does not have all the mechanical improvements desirable in a modern boiler, this type seems as well suited for the purpose intended, under the prevailing conditions, as any boiler that the writer has observed, considering cost, simplicity of construction and of operation, and ground space occupied.

INDICATIONS FOR THE FUTURE—EFFECT OF LOWERING THE B. T. U. STANDARD.

With the supply of gas oil decreasing, the demand increasing, and the price advancing, the prospects indicate that the standard of quality of carbureted water gas must be reduced. The only alternative seems to be higher priced gas, if water gas is to be made at all, and the reduction of the standard is preferable to higher costs for gas and greater use of oil. Only half as much oil per thousand feet is needed to carburet blue gas from 330 B. t. u. to 450 B. t. u. as to carburet it to 560 B. t. u. Accordingly, the oil used per run must under these circumstances be less than half the normal amount, since the total output of carbureted gas per run is also diminished. Hence with a lower standard of carbureted water-gas more combustible blast gas will be available for use outside the checker chambers; and for a carbureted gas having a heating value of 450 B. t. u. per cubic foot the heat required for carbureting the gas per given amount of blasting is less than half that required for a gas having a heating value of 560 B. t. u. per cubic foot.

Since the present tendency is toward the use of gas of a lower standard, it follows from the foregoing that, as the standard is lowered, conditions become more favorable for the use of a waste-heat boiler with a combustion chamber to utilize the excess combustible blast gas.

PROPOSED WATER-GAS SET ADAPTED FOR USE WITH BITUMINOUS COAL AS GENERATOR FUEL.

In these proposals for changes in water-gas sets to facilitate the use of bituminous coal as fuel, a set of definite size is given as an example. Most of the changes suggested have already been discussed in this paper. The chief features recommended are:

1. An oversize generator.
2. Large connections and large generator charging-door.
3. Waste-heat boiler of the vertical fire-tube type.

4. Combustion chamber between superheater and waste-heat boiler.

5. Tuyère for admitting secondary air to combustion chamber. Positive ignition and explosion safety-releases.

6. Provision for burning out the carbon in the checker chambers during fire-cleaning periods.

7. Large dust catcher.

8. Provision for the use of holdup bars for clinkering.

9. Handy quick-opening clean-out doors for base of carburetor and superheater.

10. Checker brick so supported that there will not be too large a free space at the base of the checker chambers. This will prevent an appreciable decrease in the linear velocity of the gas and avoid unnecessary deposits of carbon and fuel entrained in the gas.

11. Extended superheater.

OVERSIZE GENERATOR.

The oversize generator is designed to produce blue gas in quantities that will permit the use of the checker chambers to their full capacity; in other words, to allow as much oil per run as the checker chambers can take care of. Another object is to increase the capacity of the set.

Since the increase in the generator size is due solely to an increase in the internal diameter of the shell, it follows that for a given set of blasting conditions more air can be induced into the fire per minute during blasting than in the smaller generator. The area of the zone of complete combustion is greater. More heat is stored in the generator for a given amount of air blasting. The rate of travel of the fuel through the fire is lower for a given rate of gas production. Troubles from caking the fuel are reduced. More gas can be made per run.

LARGE CONNECTIONS AND LARGE CHARGING DOOR.

Large connections are recommended in order that the back pressure, or rather, the resistance to the passage of gas through the set, may be reduced to a minimum. This is now recognized by gas engineers as a desirable feature for all gas sets. It is specified here because one of the chief causes for a reduction of capacity (reduction in quantity of gas that can be made per unit of time) when bituminous coal fuel is used is the additional resistance offered by the fuel to the introduction of air, with a consequent reduction of the total quantity of air per minute. It is therefore essential to eliminate all unnecessary resistance when the fuel used is coal if the maximum output is desired.

A large generator charging door is suggested for the reason that, to obtain the best results, it is necessary to spread the coal properly over the surface of the fuel bed, and this can be done only, with the present type of fuel spreaders, when the door or "lid" is sufficiently large to permit its unrestricted use.

UPRIGHT FIRE-TUBE WASTE-HEAT BOILER.

The general motive for using a waste-heat boiler has already been discussed. An upright fire-tube boiler is suggested, not because it is more efficient than other types, but because many of the difficulties that would probably develop in other types seem to be more readily overcome in this type. Construction is simple and operation can be readily understood. The fire tubes do not require cleaning and are kept bright and clean by the particles of entrained matter in the waste gas—an important point when stack gas from a water-gas set is to be utilized, for considerable carbonaceous matter is usually carried over from the generator. Moreover, such a boiler occupies minimum ground space.

Present indications are that in the future the waste heat generated in the production of water gas will be utilized either in a waste-heat boiler or some other device designed to accomplish an equivalent or similar economy. Undoubtedly there is considerable room for improvement in the design of apparatus for this purpose. At present, the writer proposes that under the prevailing conditions a boiler on the order of that shown in Figure 7 be used to recover this waste heat, rather than the horizontal boiler of older design or one slightly inclined from horizontal.

COMBUSTION CHAMBER.

In utilizing the heat of combustion of the excess generator blast gas as described, some sort of combustion chamber must be provided wherein the gas can be burned before it enters the boiler tubes. This should preferably be under the boiler in ordinary conditions. However, the waste gas leaves the superheater at the top, more than 20 feet from the ground floor, hence a simple means of providing such a chamber employs a sufficiently large chamber leading from the top of the superheater to the bottom—intake—of the boiler. This is not an ideal way of constructing such a chamber particularly when consideration is given to radiation loss. Nevertheless, there seem to be some advantages in its favor. The design is simple, a means of securing an intimate mixture of air and gas is easily provided, and explosion safeties can be more readily provided than in some other designs; moreover, should an explosion take place in spite of precautions against such an occurrence, it would seemingly be localized and confined to this shell without endangering the boiler. Figure 8 shows a combustion chamber as described.

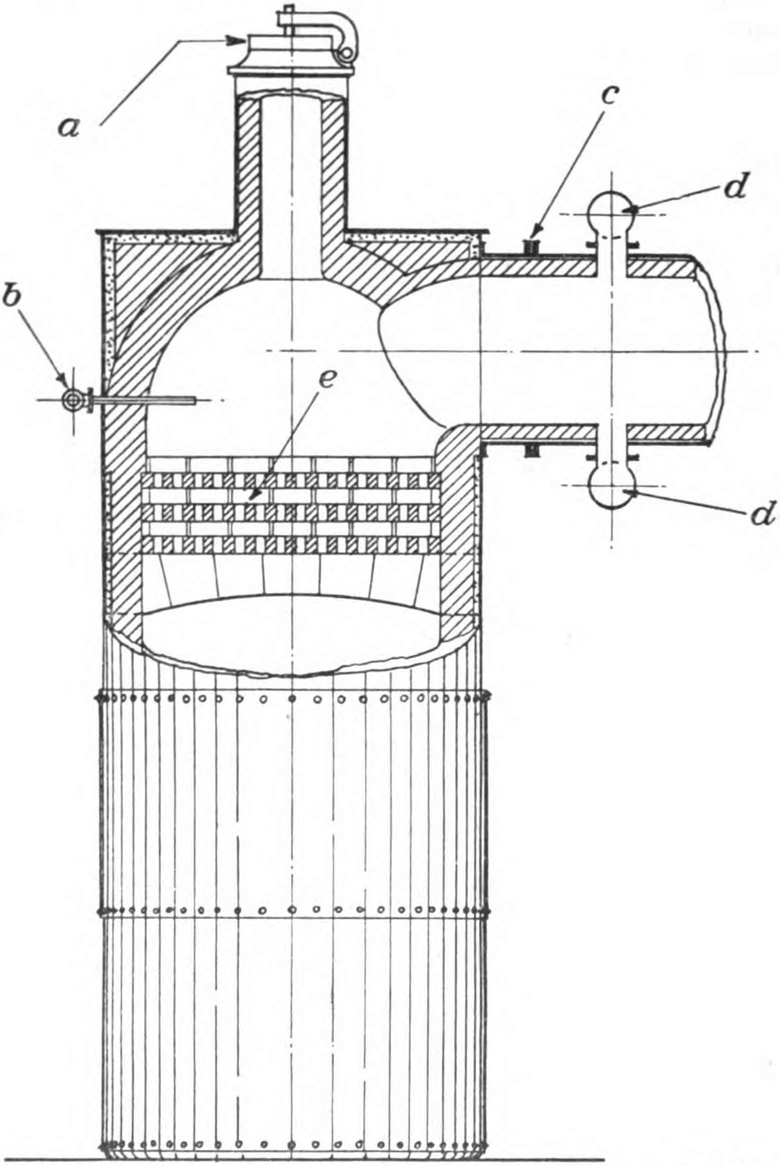


FIGURE 8.—Combustion chamber, upper part shown in section: *a*, Safety; *b*, gas jet; *c*, flange; *d*, tuyère; *e*, checker work.

The diameter of this shell is controlled by the maximum velocity that can be employed and still insure combustion. If the linear velocity of the gas is greater than the rate of flame propagation, combustion will not take place; hence, it is desirable to calculate the size of this shell for any particular set when the conditions are known.

In the offtake from superheater to combustion chamber, an opportunity is afforded to make use of a tuyère for admitting the secondary air (see Fig. 8). Thus complete combustion can be obtained with the least excess of air.

It is also essential that a positive means of igniting the gas should be provided in the upper part of the combustion chamber to avoid the sudden ignition, with explosive force, that might occur if the whole chamber were allowed to fill with an explosive mixture of gas and air before igniting. For this purpose two jets of gas entering the chamber on opposite sides (Fig. 8) are kept burning. This gas supply is under pressure and sufficient air for its combustion is premixed with it. As an additional means of insuring the ignition of the gas as it enters the combustion chamber, the latter has a few courses of widely spaced checker brick close to the gas inlet.

To provide further against explosions, safeties are supplied as shown in Figure 8. These are light in construction and so balanced as to release the gas when the pressure from within is increased abnormally, due to the sudden ignition of a large volume of gas.

PROVISION FOR BURNING OUT THE CARBON FROM CHECKER CHAMBERS.

Though all operators aim to avoid the production and accumulation of carbon in the checker work, it has not yet been found possible to eliminate its formation entirely in the production of the desired quality of gas. In some plants, especially where little attention is given to the oil spray, the accumulation of carbon is very rapid, particularly in the upper portion of the carburetor. The solution of this problem is perhaps not especially germane to the study of the use of coal in the generator, but the statement has so frequently been made that coal increases carbon troubles and thereby diminishes the life of the brick in the checker chambers that a method for eliminating this nuisance is given. The method, as previously mentioned on page 19, consists merely in providing a quick-opening door at the bottom of both carburetor and superheater whereby air can enter by natural draft during fire-cleaning periods and burn out the deposited carbon. In this manner it is possible to keep the bricks clean, a condition that not only allows the oil to be cracked under the most favorable conditions but helps to keep the daily make from decreasing, which usually happens as the carbon deposit accumulates. Plate I, the elevation of the complete set, shows the means for accomplishing this.

LARGE DUST CATCHER.

Dust catchers have been in use, particularly on small sets, for years, but it has been the practice of a number of gas companies to have the larger sets built without them. The recent practice of using higher blast pressures than formerly has made provision for dust catchers more essential than ever, and they are doubly essential with coal fuel. Such a dust catcher is shown in Plate I.

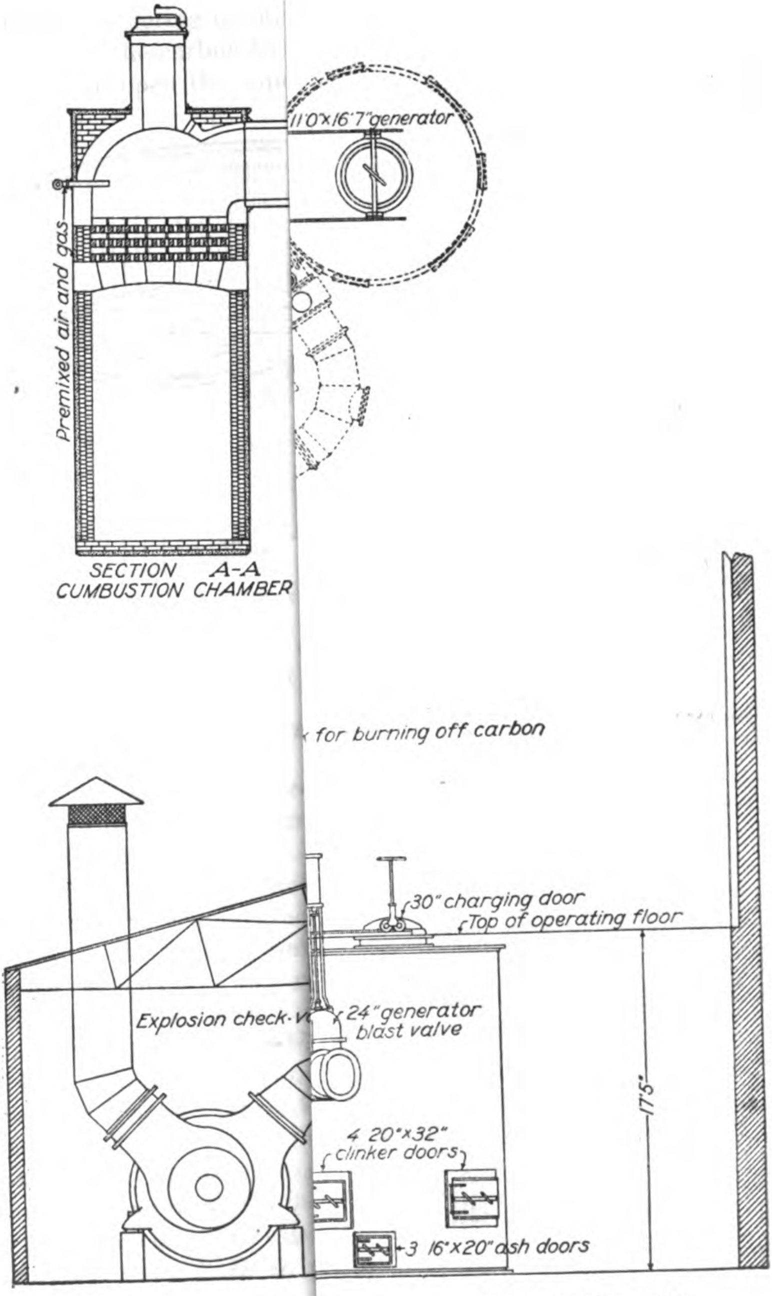
HOLDUP BARS FOR CLINKERING.

Much has been said regarding the various methods of taking care of clinkers. Some operators prefer rocking grates, others drop grates, and still others clinker bars (holdup bars) to hold up the fire while the clinker is being removed from the grates. As far as the writer has been able to learn, rocking grates are not desirable for water-gas generators, particularly with Central District bituminous coal as fuel. Occasionally benefit may be derived from their use, but the usual tendency is for the clinker to form higher in the generator above the point where the rockers can reach it. The small cleaning doors which usually accompany such an installation make proper cleaning of the fire very difficult. When he makes down runs the operator never knows the condition of the fire above the grates; and therein lies a danger of burning out the grates or of making an insufficient number of down runs to keep the clinkers off the wall. With drop grates there is danger of losing a considerable amount of hot fuel with the ash, and it is said that there is difficulty in cleaning the center of the grates—middle of the fire—without losing considerable hot fuel from the generator.

With some bituminous coals there is formed on the grates, by proper operating, a solid, easily broken clinker. With other bituminous coals, and perhaps under different operating conditions, more of an ash is formed with less solid clinker. Since many of the Central District low-sulphur coals have fairly low ash-fusion points and will, under given operating conditions, produce clinkers low in the fire on the grates, where they can be reached, it seems to be preferable to use holdup bars for clinkering. These are provided for in the proposed set.

QUICK-OPENING DOORS AT BASE OF CHECKER CHAMBERS.

A considerable amount of fuel may be blown over from the generator into the checker chambers, some of it lodging at the base of these chambers, where the linear velocity of the blast gas passing through the set is decreased. It is unquestionably an advantage to keep this gas passage clear; therefore it is recommended that one



51090°—23. (Face p. 34.)

or more doors be provided at the base of each checker chamber, so located that the deposited fuel can be quickly and completely hoed out (See Pl. I and Fig. 9). These doors should preferably be of the "quick opening" type to economize time.

During clinkering or other shutdown periods, when it is desirable to burn out the carbon from the checker chambers, it would be necessary only to open the superheater stack (raise the lid), one door at the base of each checker chamber, and the lid of the specially provided stack from the inlet to carburetor.

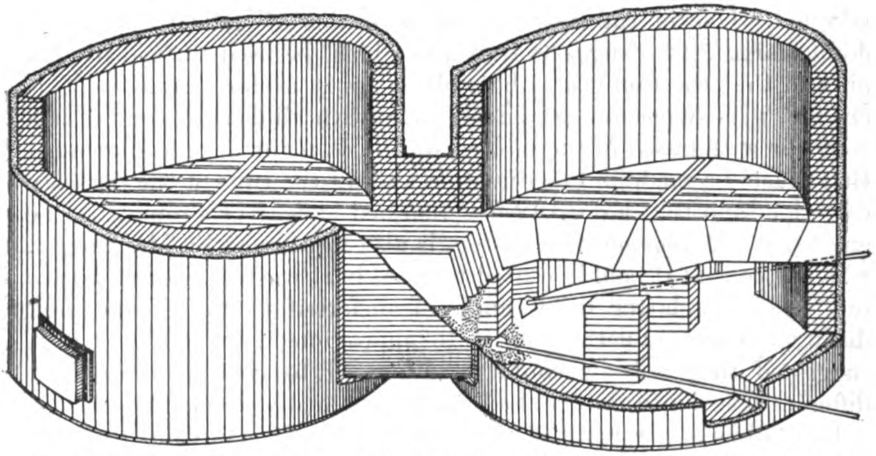


FIGURE 9.—Lower portion of checker chambers, showing location of quick-opening clean-out doors.

EXTENDED SUPERHEATER.

The carbureted gas produced when bituminous coal is used for generator fuel is, under some conditions, not as permanently "fixed" as the gas made with coke fuel. By extending the superheater the actual amount of contact of the gas and oil vapors with the hot checker brick is increased, although the velocity of the gas is not altered. The present tendency to use higher blast pressure to increase capacity has also resulted in a higher velocity of carbureted gas through the checker chambers, the bad effects of which may be remedied to a considerable extent by extending the superheater.

It is, of course, recognized that at present, with gas standards undergoing frequent alteration and the quality of oil available for gas making of an increasingly inferior grade, no preferred specifications can be evolved for the checker chambers of a set of given capacity. However, one benefit is derived from the extended superheater which is not affected by the quality or rate of input of the oil; that is, the increase in the draft on the generator. The difficulties occasioned by flame flashing in the operator's face during the charging of coal fuel should thus be relieved.

SUGGESTED CHANGES IN GENERATOR DESIGN.

Quite a number of suggestions for improvements have been made from time to time which propose more or less radical changes in both design and operation of a set. Although there is more or less merit in some of the changes advocated, apparently they have not been adopted. One of the most recent advocates of radical changes is John Harger,[3] who suggests that a hot blast be used instead of cold air and that the iron grates be omitted, as in a blast furnace. This change, it is suggested, would do away with clinkering, for the ash could be withdrawn in the molten state. It is further recommended that blasts be made in one direction and all the runs in the opposite direction, and that a deep 12-foot fuel bed instead of a 6-foot bed be employed. A regenerative system is also mentioned by Mr. Harger, who states that it could be used to store heat wasted as combustible blast gas, the latter being finally transferred to the steam used during the run, superheating it to approximately 1,000° C. It is suggested that hot air could be admitted to good advantage at different levels into the fuel bed through specially provided openings.

Regardless of the merit of these suggestions, it is obvious that the original investment for the apparatus advocated would be considerably greater than for a set without these improvements, which alone is an item that is given much consideration, particularly at the present time. Probably some of the numerous suggestions that have been made for improving the present sets by radical changes will eventually be accepted.

Although the various ideas can not be discussed here individually, one seems worth noting, namely, fusing the ash and removing it as a liquid. When it is considered that in some plants from six to eight hours a day per set are consumed in clinkering, the enormously increased capacity obtainable by such a procedure is at once evident. This idea has been worked on and developed to a certain extent in producer-gas investigations. Blast furnaces with light charges of ore and flux have been used for the production of gas, and their operation is reported to be successful. What the cost was has not been made known. Many of the Central District bituminous coals have a readily fusible ash and would probably require a minimum amount of flux when used in such a generator.

A number of other investigators have expressed their ideas, some of which have been patented, but nearly all have the following aims in common: To increase the capacity of a set of given size, to produce the minimum amount of CO_2 in the blue gas, to maintain a uniformly high temperature in the fuel bed, to produce a minimum amount of excess combustible blast gas, and to diminish or eliminate clinker troubles.

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[3] Harger, John. Shortcomings of the water-gas process: Chem. Age, vol. 1, 1919, pp. 30–31; Jour. Soc. Chem. Ind., vol. 38, 1919, pp. 616–617.

Some advocate a double generator, blasting simultaneously up through each fuel bed but making the run by forcing the steam up through one fuel bed and thence down through the other; in other words, the generators are operated in parallel during the blow and in series during the run. The advantage claimed is that the benefits of a deep fuel bed are obtained during a run and of a shallow bed during the blow. The Kramers and Aarts process makes use of this principle. It has also been recommended that air be supplied to the center of the fuel bed, as well as from beneath it, to obtain a more uniform temperature in the generator. While the advantage to be gained is apparent, it has proved impracticable so far.

Most of the processes devised for using coking coal as generator fuel admit it into a retort of some type wherein it is supposed to be coked before reaching the generator proper, after which it is used in the regular way for the production of blue gas. The coal is coked either by the hot blast gases passing around the retort or over the fuel in the retort, or by forcing some of the gas through the coking mass. These processes, in general, have not yet proved satisfactory on account of the difficulty of coking the coal and the trouble in getting the coked mass to perform as desired. Sufficient heat is not supplied by the sensible heat of the blast gas when passed around a retort to coke the coal inside in the quantities required to supply the generator.

Even though it may be a long time before sets that are radically different from the present ones are generally used, the high price of coke, which in turn has caused a great increase in the amount of coal used as generator fuel, has cleared the way for the development of water-gas sets particularly adapted for use with bituminous coal.

SUMMARY AND CONCLUSION.

1. At the present time, with the prevailing high price of coke, water gas can unquestionably be made from bituminous coal more cheaply than from coke.

2. As prices of coal and coke advance, with an increasing margin of difference between them, the economy that can be realized from the use of coal as generator fuel increases.

Figure 1 is a chart from which the actual saving from the use of coal fuel can be quickly determined for any particular fuel when the coal, coke, and oil costs are within the wide range used in preparing the chart.

3. When coal is substituted for coke and the same methods of operating used as with coke, there is an appreciable waste of fuel, which can be eliminated.

4. The amount of this waste per thousand feet of gas made will increase as the standard of gas is lowered. The present tendency is toward a lower standard for city gas.

5. One method of eliminating waste—the use of a waste-heat boiler with combustion chamber—is suggested and discussed in this paper. The method is not offered as the only way or as the best way, but as a means to an end, with the hope that it will bring forth additional suggestions that will help to evolve a better method for accomplishing the desired results.

In figuring the benefit in dollars to be derived from the use of the waste-heat boiler, the aim has been to be conservative. The temperature—760° F.—assumed for the waste gas leaving the boiler is perhaps high, and that of the gas leaving checker chambers and entering the combustion chamber is low, giving a smaller drop in the temperature of the gases passing through the boiler than might be obtained in practice. However, this may be offset by the fact that the volume of producer gas may not be so great as figured, depending on the coal used and the method of operating. There is also a correction for moisture in the air and gas to be made in practice, which has not been made here for the sake of clearness. Moreover, with the existent variables, the exact radiation loss per thousand feet can not readily be calculated. The cost of coal per ton (boiler fuel) is also intentionally taken at a low rather than at a high value. The cost of the complete installation, as described, is greater than that of the present water-gas sets, hence in arriving at an exact net saving the interest on the greater investment as well as a larger depreciation charge will have to be taken into consideration.

PUBLICATIONS ON PRODUCER GAS AND WATER GAS.

A small supply of the following publications of the Bureau of Mines has been printed. Requests for all publications can not be granted.

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PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

Bulletin 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker, compiled and revised by H. M. Wilson. 1911. 77 pp., 4 pls., 12 figs.

BULLETIN 203. Central District bituminous coal as water-gas generator fuel, by W. W. Odell and W. A. Dunkley. 1923. 89 pp., 10 figs.

TECHNICAL PAPER 9. The status of the gas producer and of the internal-combustion engine in the utilization of fuels, by R. H. Fernald. 1912. 42 pp., 6 figs.

TECHNICAL PAPER 246. Water-gas apparatus and the use of Central District coal as generator fuel, by William W. Odell. 1921. 28 pp., 1 pl., 2 figs.

TECHNICAL PAPER 284. Coke and coal mixtures as water-gas generator fuel, by W. W. Odell. 1922. 32 pp., 4 pls., 2 figs.

TECHNICAL PAPER 304. Water-gas tar emulsions, by W. W. Odell. 1923. 51 pp., 6 figs.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 58 pp., 1 pl., 16 figs. 10 cents.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. 393 pp., 12 pls., 250 figs. 65 cents.

BULLETIN 31. Incidental problems in gas-producer tests, by R. H. Fernald, C. D. Smith, J. K. Clement, and H. A. Grine. 1911. 29 pp., 8 figs. 5 cents.

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TECHNICAL PAPER 120. A bibliography of the chemistry of gas manufacture, by W. F. Rittman and M. C. Whittaker, compiled and arranged by M. S. Howard. 1915. 30 pp. 5 cents.

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